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Attention-based motion perception and motion adaptation: What does attention contribute?

Frans A.J. Verstraten [a,c,*], Hiroshi Ashida [b,c]

[a] Psychonomics Division, Helmholtz Institute, Faculty of Social Sciences, Universiteit Utrecht, Heidelberglaan 2, NL-3584 CS Utrecht, The Netherlands
[b] Graduate School of Letters, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan
[c] ATR Human Information Sciences Research Laboratories, 2-2-2 Hikari-dai, Seika-cho, Soraku-gun Kyoto, 619-0288, Japan

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Abstract

Attention-based motion perception refers to the phenomenon that a stimulus with ambiguous motion energy can be seen to move in a direction that is under attentive control of the observer. The role of attention is obvious when the stimulus is ambiguous: it makes the stimulus move in one direction. The goal of the current experiment is to investigate what the contribution of attention under attentive tracking conditions actually is, especially while viewing-time progresses. We had our observers look at a circular array of four evenly spaced discs whose motion direction was biased in the clockwise direction. Observers either viewed the stimulus moving around a circular path passively or actively. In the latter case they attentively tracked one of the discs. The observer's task was to indicate the perceived direction of motion. As time progresses, this kind of stimulus will undergo spontaneous motion direction reversals. We analyzed the time course of the reversals and show that actively attentive tracking the stimulus massively delays the reversal time. These results suggest that attention can temporarily overrule lower level adaptation.

Keywords: Attention; Apparent motion; Tracking; Aftereffects; Adaptation

1. Introduction

The mechanisms underlying the perception of movement are dependent on the *type* of motion that has to be detected. Several types of motion mechanisms have been proposed. To name a few: short range and long range (Braddick, 1974; Braddick, 1980) or mechanism I and II (Anstis, 1980), Fourier and non-Fourier mechanisms (e.g. Chubb & Sperling, 1988) and first-order and second-order mechanisms as suggested by Cavanagh and Mather (1989).

Cavanagh and Mather also introduced another way to categorize motion perception mechanisms. They made a distinction between *passive* and *active* motion processes. In short, one could say that passive motion perception 'just happens'. In the case of passive motion perception it suffices to open the eyes and if there is an unambiguous displacement of an object, it will be perceived as moving in a particular direction. Active motion perception, on the other hand, requires a conscious effort of the observer. One of the phenomena that falls into this category was first described in 1912 by Wertheimer (1912) and is now often referred to as *attention-based apparent motion* (e.g. Verstraten, Cavanagh, & Labianca, 2000) *or attention-based motion* in the case of a continuous stimulus (Cavanagh, 1992).

In a typical attentive tracking experiment, observers are required to maintain fixation on a point in the center

* Corresponding author. Address: Psychonomics Division, Helmholtz Institute, Faculty of Social Sciences, Universiteit Utrecht, Heidelberglaan 2, NL-3584 CS Utrecht, The Netherlands. Tel.: +31 30 253 3371; fax: +31 30 253 4511.
E-mail addresses: f.a.j.verstraten@fss.uu.nl (F.A.J. Verstraten), ashida@bun.kyoto-u.ac.jp (H. Ashida).

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of the configuration and attentively track, for example, one of the four evenly spaced sails of a windmill stimulus, which is displaced by 45 deg between successive frames. It requires a little training (a few trials) to optimize, but observers can easily do this task and it results in a clear percept of unidirectional rotational motion. Although observers have a strong impression that they are making eye-movements, Verstraten, Hooge, Culham, and van Wezel (2001) have shown that there are no systematic eye-movements that can explain the percept of motion during attentive tracking (see also Cavanagh, 1992).

In Fig. 1 we show a modern version of Wertheimer's stimulus. Discs instead of Wertheimer's sails/lines have the advantage that they give a more localized region for observers to attend to.

We know that the system underlying attentive tracking is rather different from the standard motion detection systems. As said, attention is required to disambiguate a bi-stable stimulus (see also Wertheimer in Shipley, 1961, p. 1070). Moreover, Culham, Verstraten, Ashida, and Cavanagh (2000) have shown that prolonged tracking of such a stimulus results in a motion aftereffect, an illusory movement opposite of the perceived direction (Anstis, Verstraten, & Mather, 1998; Mather, Verstraten, & Anstis, 1998), but only for *dynamic* test patterns. This indicates that it is likely that there is adaptation at a different, possibly higher, stage of motion processing (see also Nishida & Sato, 1995).

In order to investigate the contribution of attention to motion mechanisms, one has to select an appropriate stimulus. We need to compare a passive motion perception condition with an active motion perception condition (with and without attentive tracking). Since there is no passive *motion* perception for directionally ambiguous stimuli—which results mainly in directionless flicker—we used directionally biased stimuli in which we displaced a sequence of four equally spaced discs 30 deg in the clockwise direction (see Fig. 2). In this case, observers perceive a clear motion direction under passive viewing conditions as well. This condition was compared with the condition in which the observers were presented with exactly the same stimulus but instructed to track one of the discs along the circular path.

For this stimulus there is also motion energy/correspondence strength in the opposite direction; a displacement of 30 deg clockwise (CW) implies a displacement of 60 deg in the CCW direction. Indeed, after passively viewing or attentively tracking for a period of time, the motion percept in the CW direction is followed by a reversal to the CCW direction. This will last for some time and the direction will change to the CW direction again, and so on. Both directions are competing for what is sometimes called perceptual awareness (e.g. Kanwisher, 2001). This phenomenon is also related to an illusory motion reversal reported by Kline, Holcombe, and Eagleman (2004) but the reversal dynamics do not show the typical gamma distribution found for multi-stable stimuli like ambiguous figures (e.g. Borsellino, De Marco, Allazetta, Rinesi, & Bartolini, 1972) or stimuli under binocular rivalry conditions (e.g. Levelt, 1965).

In the current experiment we use this perceptual reversal to look into the role of attention under passive and active viewing conditions. Also, we investigated another temporal aspect, namely the effect of tracking/viewing time: What is the time course of the alternations? Does prolonged viewing result in a situation

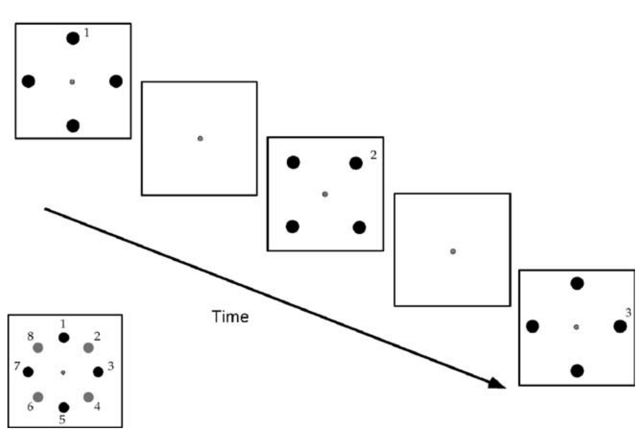

Fig. 1. Example of a modern version of Wertheimer's stimulus (for Wertheimer's original stimulus, see Fig. 1 in Verstraten et al., 2000). Two arrays of four discs are alternated in time and space (see inset: even and odd sets on alternate frames, separated by a blank ISI) so that eight 'steps' are needed to complete a full revolution. Passive viewing will lead to the impression of back and forth motion or random motions. Attentive tracking, however, makes a selected disc appear to follow a path around the display in a direction that is under the voluntary control of the observer.

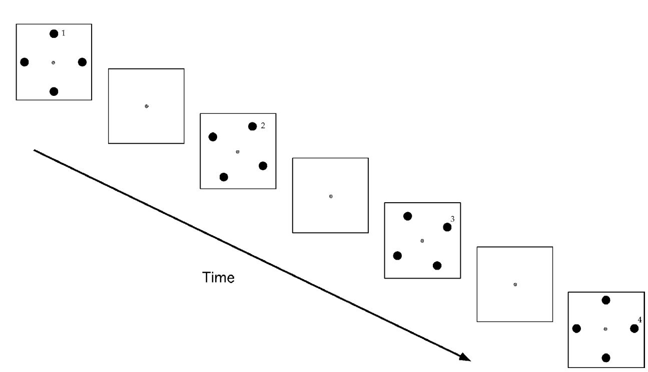

Fig. 2. An example of a biased stimulus where the steps between frames is not 45 deg as in Fig. 1 but 30 deg. Initially, this arrangement of the stimulus gives a strong impression of motion in the clockwise direction, both under passive viewing as well as active tracking conditions.

where no motion is perceived, only flicker? (e.g. Anstis, Giaschi, & Cogan, 1985; Kolers, 1972).

2. Experiment

2.1. Methods

2.1.1. Apparatus and stimuli

Stimuli were created on a Macintosh G3 using Vision Shell software and displayed on a Sony 21″ screen. The screen refresh rate was 120 Hz, and the responses were collected at 30 Hz (observers continuously indicated the perceived direction by pushing one of two designated keys on the keyboard, see below). We used the stimulus configuration as displayed in Fig. 2. The stimulus was a circular array of discs whose direction was strongly biased in the clockwise direction. To introduce a directional bias in the stimulus, such that one direction is favored over the other, we displaced the dots 30 deg instead of the ambiguous 45 deg (see Fig. 1). Thus, after three 30 deg steps the stimulus returns to the original configuration (see Fig. 2). Initially, when observers are presented with this stimulus they always report motion in the clockwise direction (e.g. Ullman, 1979). As described before, there is also motion energy/correspondence strength in the opposite direction; a displacement in the 30 deg direction implies a displacement in the 60 deg in the counter clockwise direction (CCW). The diameter of a single disc was 1.1 deg, and that of the circular array 11.2 deg. The luminance of the discs was 90 cd m^{-2}, placed on a 18 cd m^{-2} background. The discs were displaced every 167 ms with an interstimulus interval of 83 ms. A fixation dot was always present. The viewing distance was 70 cm for all experiments.

2.1.2. Observers

The authors and one observer who was naïve as to the purpose of the experiment, participated in the experiment. All had normal or corrected to normal vision.

2.1.3. Procedure

Observers sat in front of the screen and watched the stimulus while maintaining steady fixation using a head and chin rest. In general, after some time of passively viewing or attentively tracking, the motion percept in the CW direction is followed by a reversal to the CCW direction. This will last for some time, and then the perceived direction will change to the CW direction again, and so on. There were two main conditions.

2.1.4. Passive viewing

Observers were instructed to fixate and indicate the perceived direction. The naïve observer was told that the direction of rotation was under control of the experimenter. The perceived direction was indicated using the computer keyboard.

2.1.5. (Active) Attentive tracking

First, the observer was trained in attentive tracking of directionally biased stimuli. These stimuli were presented only for a few seconds so that no reversal would occur. To find out whether the observers were accurately tracking, we used the method as described in Verstraten et al. (2000). In short, observers fixate a dot in the center of the display. The trial starts with a little marker disc presented in the center of one of the discs. This marker disc makes successive steps in a defined direction when the set of four discs is replaced by the next set of four. The observers' task is to attentively track the disc in which the marker appears. After a few steps the marker disappears and observers try to attentively track the disc along the path that was indicated by the marker disc. After a few seconds the marker appears again for a short time, either in the correct location for accurate tracking, or one step before or after the correct location. The observers have to indicate whether the test disc appeared in the disc they were tracking or not. For the conditions in the current experiment, observers performed this task with perfect accuracy. During the actual experiment, the marker disc was not present.

Before the experiment, observers were instructed to try and maintain attentive tracking in the clockwise direction. Due to adaptation effects, the direction will change to the CCW direction. The observers were asked to view the CCW direction passively and, as soon as the discs changed back to the CW direction, to start tracking one of the CW moving discs again. Irrespective of the total time, an experiment al session continued until the computer registered 40 reversals of direction for off-line analyses. Each condition was presented four times.

2.2. Results

2.2.1. Main effect

In Fig. 3, we show a sample from the data obtained from the three observers. The figure represents the perceived (indicated) direction of the stimulus. Recall that the stimulus (four evenly spaced discs) made clockwise (CW) steps of 30 deg along a circular path.

The figure illustrates two main observations. First, initially, the observers always see the CW direction, that is, the dominant motion direction. After some time a reversal occurs, followed by another one, etc. Second, by illustrating it this way, it is easy to see that our main effect—the effect of attention—is large. The direction as indicated by the line with the smaller amplitude represents the first 10 reversals in the passive viewing condition. The line with the larger amplitude represents the perceived direction under attentive tracking conditions

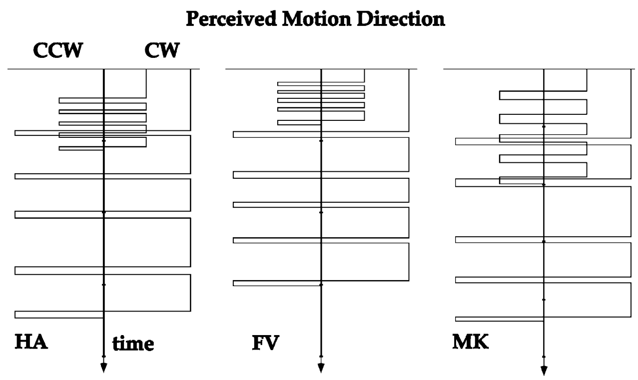

Fig. 3. Results for all observers (the first 10 out of 40 reversals). The figure shows the perceived direction as a function of time. The lines with the smaller amplitude represent the time a certain direction is perceived in the passive viewing condition. The ones with the larger amplitude show the same for the active attentive tracking condition. It is clear that attentive tracking massively delays the moment at which a direction reversal occurs (at least for the reversals from the CW to the CCW direction) (see text for details).

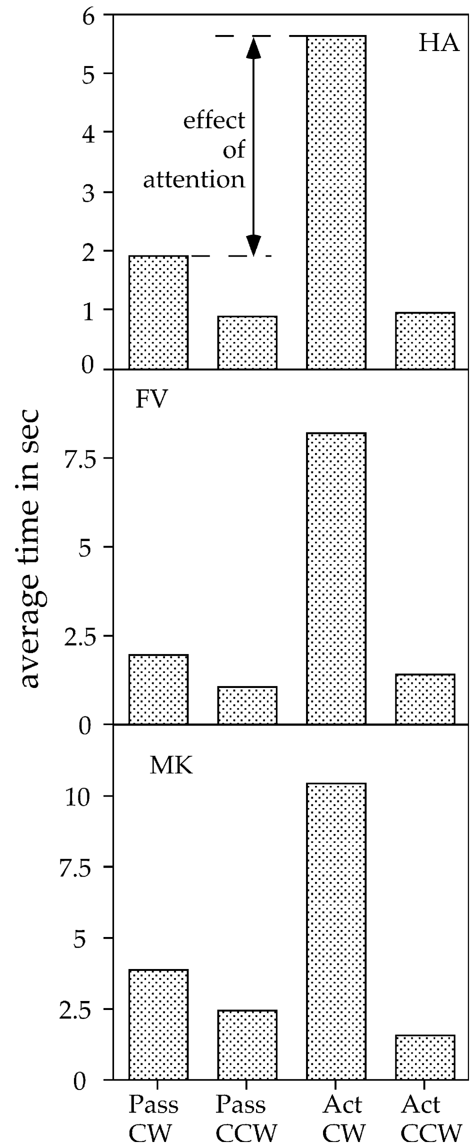

Fig. 4. Illustration of the main effect for all observers. The average time a specific direction (CW and CCW) is seen under two conditions (passive viewing and active tracking: keep in mind that in the active tracking condition the CCW direction is passively viewed). The time that CW-direction is perceived is much longer in the active tracking condition. This is the effect of attention as indicated by the arrow in the left panel.

(amplitude is only used for clarity). It shows that tracking the stimulus with attention substantially delays the moment that the perceived direction reverses. For example, for observer FV the first 10 direction reversals in the passive condition take less time than the first reversal in the active attentive tracking condition.

If we, for the time being, ignore the time-course of the reversals we can see the main effect of attentive tracking. In Fig. 4 we plot the average time a certain direction (CW or CCW) is perceived for two conditions: passive viewing and active attentive tracking. The graphs show that the effect of attention is massive, and that attention is able to overrule adaptation effects that would normally dominate the percept under passive viewing conditions. We will come back to this in the General Discussion.

2.2.2. The time course and competing signals

An interesting question concerns the effect of *extended* viewing on the time between the reversals. That is, the time a certain direction is perceived as viewing time progresses. In Fig. 5, we plot the data as a function of viewing time interval. For reasons of clarity, we collapsed the reversals into five groups. That is, each data point represents the average time of four reversals. For example, grouped average 1 for the Pass CCW-condition, represents the average time the CCW direction is perceived for the first four times (see inset Fig. 5); grouped average 2 for 5–8, etc.

The data show a decrease in the duration that a certain direction is perceived as time progresses for the active tracking condition (Act CW). Whether this decrease continues or levels out is less clear from this representation. This is true for the data points in the other conditions as well.

As mentioned before, the stimulus has *energy* or *correspondence strength* in two directions. The strength in the 30 deg CW direction is initially greater than in the 60 deg CCW direction, hence the fact that observers always indicate CW motion when the stimulus is started. Of these two competing signals the CW direction initially wins. However, extended viewing will result in adaptation. We assume that adaptation only takes place for the neural substrates involved in the *perceived* direction. This is probably not true, but not important for our argument. When adaptation for the perceived direction becomes deeper in time, there will be a point at which

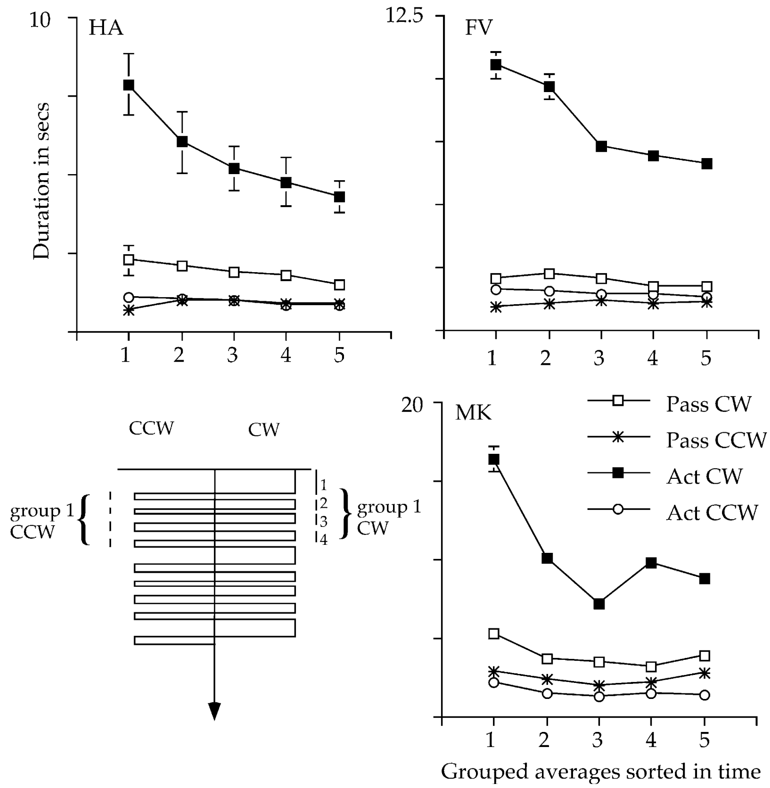

Fig. 5. Time course of perceived directions between reversals.

the correspondence strength of the CCW direction is higher than for the adapted CW direction. As a result, a reversal will occur and the CCW direction will be perceived. At that time, the CW direction—which is not perceived anymore—will start to recover from adaptation and the neural substrates for the CCW direction—which is now perceived—will begin adapting. At one point in time the substrates underlying the CCW direction will reach a certain adaptation level, and at the same time, those responsible for the CW direction will have recovered so much, that the correspondence strength of the CW direction is again larger than for the CCW direction. As a result, again a direction reversal will occur.

This alternation process potentially (and theoretically, given our line of reasoning above) has an interesting outcome. The neural substrates responsible for the clockwise direction will not have to recover all the way back to baseline: they only have to recover such that they become stronger (again) than the signal that codes for the perceived CCW motion. If absolute strength is the determining factor, at that time a reversal is expected. Again, following our line of reasoning, this process should get to a point where the direction reversals follow each other so fast that the stimulus appears to flicker/oscillate, as found for example by Anstis et al. (1985) for two-positional apparent motion.

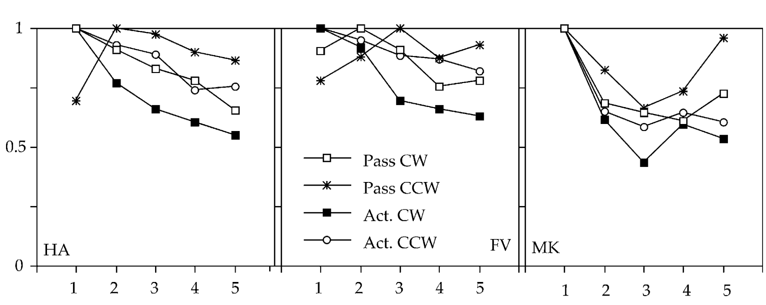

Fig. 6. Time course of perceived directions between reversals. In order to show the effects of the short durations (especially those in the CCW direction), we normalized all durations, where 1 is taken as the maximum duration of the time between reversals for each condition and each observer.

The results show that in general the time between reversals does not become shorter. Even after 40 reversals, no flicker is perceived. A different representation of the data is shown Fig. 6. In order to show the differences for the perceived directions that can only be seen for a rather short time, we normalized the durations for all conditions. Again, even with this representation there is no evidence that the time between reversals is decreasing while time progresses, at least not in such a way that they will become short enough to appear as flicker. Observer HA has the only real gradual decrease, FV levels out, and observer MK even shows an increase as time progresses. Due to the nature of the current experiments, that is, the inherently short durations of reversals (especially in the passive condition) the results are not conclusive. However, 40 reversals take a considerable period of time. One observer (FV) viewed the stimulus for 15 min and still this did not lead to flicker.

3. General discussion

The main question we wanted to answer in this paper concerns the role of attention in perceiving motion. We have shown that the normal competition between different directions, which shows itself in direction reversals, can be modulated by attention. We found that for an apparent motion stimulus, the effect of attentive tracking is massive. More specifically, the perception of motion in the attentively tracked direction lasts much longer than in the case of passive viewing: it overrules lower level signals for reversals. This result suggests that one of the roles of attention is to maintain an important perceptual event, despite lower level motion adaptation. This is not overly surprising but the role of attentive mechanisms become even more impressive if one considers it in light of the effect of higher level adaptation.

Previously, it has been shown that there is an aftereffect build-up due to attentive tracking. This aftereffect is likely to be generated at a higher level of visual motion processing (Culham et al., 2000). In our case, where we have a CW biased stimulus that has to be tracked in the CW direction, there will be two sources of adaptation. A lower level source/gain-control set by the motion energy in the stimulus and a higher level source set due to attentive tracking. Both these adaptation effects will push the percept to change its direction opposite to the CW movement of the adaptation pattern. Yet, although both forces work in the opposite direction (CCW), the substrates underlying attentive tracking are apparently strong enough to delay the reversal substantially.

Although the experiment was not specifically designed to address this issue, the second question that captured our interest concerned the dynamics of the competition between the neural correlates for both directions. If adaptation in the perceived direction would result in a reversal as soon as the response in the other direction becomes larger, it predicts that reversals would occur faster and faster up until a point that the stimulus starts flickering, especially for the passive condition. We found that the percept did not fall into complete flicker at all, even after extended viewing. Why this differs from results as reported by Anstis et al. (1985) is not clear and requires further investigation. There is even more reason to look into attention based motion perception. Recent research has indicated direction reversals can be induced immediately by visual or auditory transients. That is, while an observer is tracking an ambiguous pattern like the one in Fig. 1, a transient results in a direction change of the perceived stimulus Kanai, Moradi, Shimojo, and Verstraten (in press).

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